MARTIN
NUCLEAR DIVISION

BALTIMORE 3, MARYLAND

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PROJECT ENGINEER

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# FOREWORD

This quarterly report is submitted by the Nuclear Division of The Martin Company to the Nuclear Power Field Office, Engineer Research and Development Laboratories, U.S. Army Corps of Engineers, in compliance with Contract DA-44-009-ENG-3581. The report describes progress from January through March 1961 in the ANPP Corrosion Program.

## CONTENTS

## SUMMARY

The first series of three 2000-hour autoclave tests on Monel and nickel coupons was completed. In one autoclave, charged with water containing 1000-ppm chloride and 15-ppm oxygen, the Monel coupon in the vapor phase experienced mild pitting. Average corrosion rates were: for Monel, 0.51 mdd; and for nickel, 0.37 mdd (milligrams per square decimeter per day).

A 2000-hour autoclave test on nickel, under conditions which caused pitting of Monel, was initiated. A total of 672 hours of testing was accumulated.

The corrosion loop operated virtually continuously during the quarter. Average operating time efficiency (OTE) was approximately 84%. The only major shutdown was caused by failure of terminals on one of the primary 50-kw line heaters.

Testing of the bimetal model vessels (MOD SX-4) and the Inconel model vessels (MOD SX-7) continued. Cumulative test time to date is approximately 2350 hours.

Testing of the bimetal miniature vessels (MIN 15 and 16) and the Inconel miniature vessels (MIN 10 and 11) continued. Average cumulative test time is approximately 2420 hours.

Analysis of heat transfer data was started. Preliminary results for the model vessels indicate that large effects on heat transfer due to scaling have not occurred.

# I. HEAT EXCHANGER CORROSION PROGRAM *

The objectives of the heat exchanger corrosion program are:

(1) The determination of the effect of secondary water conditions on heat exchanger life, using various exchanger materials. The most severe water conditions a  limited to 1000-ppm chloride with air cover gas and air-saturated water.

(2) The examination of the technique of test heat exchanger fabrication.

(3) The recommendation of materials and service conditions for operating units.

Model and miniature heat exchangers currently under test, fabrication or design are shown in Table 1.

## A. AUTOCLAVE TESTS

### 1. Testing

The first series of 2000-hour autoclave tests was completed. The conditions for these three tests are summarized below:

| Test No. | Material | Time (hr) | Oxygen (ppm) | Chloride (ppm) |
|---|---|---|---|---|
| 1 | Monel | 2000 | 1 | 10 |
| 2 | Monel | 2000 | 15 | 1000 |
| 3 | Nickel | 2000 | 1 | 10 |

pH adjusted to 10 with $Na_3PO_4$ in all tests.

Figures 1, 2 and 3 show the appearance of the coupons as they were removed from the autoclaves. Post-test analysis results for these tests are given in the following section.

A 2000-hour test on nickel was initiated during the quarter. Conditions for this test are 1000-ppm chloride, 15-ppm oxygen and pH adjusted to 10 with $Na_3PO_4$. At the end of the quarter, 672 hours of test time had been accumulated.

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*J. McGrew, J. Mueller, M. Norin, E. Jules, T. Page, W. Taylor

## TABLE 1
## Test Heat Exchanger Status

| Heat Exchanger Type | Number | Tube Material | Tube Sheet Material | Overlay | Shell Material | Water Conditions | Status* |
|---|---|---|---|---|---|---|---|
| Steam Generator | MOD SG-1 | 304 SS | 304 SS | 308 SS | 304 SS | 1 | Service--1927 hr (sectioned) |
| Superheater | MOD SH-1 | 304 SS | 304 SS | 308 SS | 304 SS | 1 | Failed--1927 hr (sectioned) |
| Steam Generator | MOD SG-2 | Bimetal[a] | Carbon Steel | 308 SS | Carbon Steel | 1 (3) | Service--5041 hr |
| Superheater | MOD SH-2 | Bimetal [a] | Carbon Steel | 308 SS | Carbon Steel | 1 (3) | Service--5041 hr |
| Steam Generator | MOD SG-3 | 304 SS | 304 SS | 308 SS | 304 SS | 2 | Fabrication complete |
| Superheater | MOD SH-3 | 304 SS | 304 SS | 308 SS | 304 SS | 2 | Fabrication complete |
| Steam Generator | MOD SG-4 | Bimetal[a] | Carbon Steel | 308 SS | Carbon Steel | 13 | Under test--2413 hr |
| Superheater | MOD SH-4 | Bimetal[a] | Carbon Steel | 308 SS | Carbon Steel | 13 | Under test--2413 hr |
| Steam Generator | MOD SG-5 | Croloy 16-1 | A350LF-1 | 308 SS | Carbon Steel | 3 | Service--4253 hr |
| Superheater | MOD SH-5 | Croloy 16-1 | A350LF-1 | 308 SS | Carbon Steel | 3 | Service--4253 hr |
| Steam Generator | MOD SG-6 | Inconel | AISI-1020 CS | Inco "A" | Carbon Steel | 3 | Service--381[illegible] hr |
| Superheater | MOD SH-6 | Inconel | AISI-1020 CS | Inco "A" | Carbon Steel | 3 | Service--381[illegible] hr |
| Steam Generator | MOD SG-7 | Inconel | AISI-1030 CS | Inco "A" | AISI-1030 CS | 12 | Under test--2308 hr |
| Superheater | MOD SH-7 | Inconel | AISI-1030 CS | Inco "A" | AISI-1030 CS | 12 | Under test--2308 hr |
| Steam Generator | MOD SG-8 | Monel or Nickel | SA-105-II | Monel or Nickel | SA-212-B | | In design |
| Superheater | MOD SH-8 | Monel or Nickel | SA-105-II | Monel or Nickel | SA-212-B | | In design |
| Miniature | MIN-1 | 304 SS | 304 SS | 308 SS | 304 SS | 4 | Failed--42 hr |
| Miniature | MIN-2 | 304 SS | 304 SS | 308 SS | 304 SS | 5 | Service--1020 hr |
| Miniature | MIN-3 | 304 SS | 304 SS | 308 SS | 304 SS | 6 | Failed--1085 hr |
| Miniature | MIN-4 | 430-M (B W) | 15 Cr, 0.17 Ni | 430-M (B W) | 16 Cr, 0.20 Ni | 7 | Failed--2578 hr |
| Miniature | MIN-5 | 430-M (B W) | 15 Cr, 0.17 Ni | 430-M (B W) | 16 Cr, 0.20 Ni | 8 | Failed--941 hr |
| Miniature | MIN-6 | 430-M (B W) | 15 Cr, 0.17 Ni | 430-M (B W) | 16 Cr, 0.20 Ni | 9 | Service--2707 hr |
| Miniature | MIN-7 | Bimetal[a] | Carbon Steel | 308 SS | Carbon Steel | 4 | Service--3250 hr |
| Miniature | MIN-8 | Inconel | Inconel | Inco "A" | Inconel | 10 | Service--5290 hr |
| Miniature | MIN-9 | Inconel | Inconel | Inco "A" | Inconel | 11 | Service--2631 hr |
| Miniature | MIN-10 | Inconel | Inconel | Inco "A" | AISI-1030 CS | 14 | Under test--2433 hr |
| Miniature | MIN-11 | Inconel | Inconel | Inco "A" | AISI-1030 CS | 15 | Under test--2413 hr |
| Miniature | MIN-12 | Monel | AISI-1020 CS | Nickel | AISI-1030 CS | 2 | Fabrication complete |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Miniature | MIN-3 | 304 SS | 304 SS | 308 SS | 304 SS | 6 | Failed--1085 hr |
| Miniature | MIN-4 | 430-M (11 W) | 16 Cr, 0.17 Ni | 430-M (11 W) | 16 Cr, 0.20 Ni | 7 | Failed--2578 hr |
| Miniature | MIN-5 | 430-M (11 W) | 16 Cr, 0.17 Ni | 430-M (11 W) | 16 Cr, 0.20 Ni | 8 | Failed--941 hr |
| Miniature | MIN-6 | 430-M (11 W) | 16 Cr, 0.17 Ni | 430-M (11 W) | 16 Cr, 0.20 Ni | 9 | Service--2707 hr |
| Miniature | MIN-7 | Bimetal[a] | Carbon Steel | 308 SS | Carbon Steel | 4 | Service--3280 hr |
| Miniature | MIN-8 | Inconel | Inconel | Inco "A" | Inconel | 10 | Service--5290 hr |
| Miniature | MIN-9 | Inconel | Inconel | Inco "A" | Inconel | 11 | Service--2531 hr |
| Miniature | MIN-10 | Inconel | Inconel | Inco "A" | AISI-1030 CS | 14 | Under test--2433 hr |
| Miniature | MIN-11 | Inconel | Inconel | Inco "A" | AISI-1030 CS | 15 | Under test--2413 hr |
| Miniature | MIN-12 | Monel | AISI-1020 CS | Nickel | AISI-1030 CS | 2 | Fabrication complete |
| Miniature | MIN-13 | Monel | AISI-1020 CS | Nickel | AISI-1030 CS | 2 | Fabrication complete |
| Miniature | MIN-14 | Monel | AISI-1020 CS | Nickel | AISI-1030 CS | 2 | Fabrication complete |
| Miniature | MIN-15 | Bimetal | AISI-1020 CS | --- | AISI-1030 CS | 16 | Under test--2410 hr |
| Miniature | MIN-16 | Bimetal | AISI-1020 CS | --- | AISI-1030 CS | 13 | Under test--2424 hr |
| Miniature | MIN-17 | Nickel | AISI-1020 CS | Nickel | AISI-1030 CS | 2 | Fabrication complete |
| Miniature | MIN-18 | Nickel | AISI-1020 CS | Nickel | AISI-1030 CS | 2 | Fabrication complete |
| Miniature | MIN-19 | Nickel | AISI-1020 CS | Nickel | AISI-1030 CS | 2 | Fabrication complete |

NOTES:

(a) Primary Side--Type 304 SS

Secondary Side--Carbon Steel

1. Chloride--40-50 ppm
   Phosphate--40-80 ppm
   Sulfite--0-10 ppm
   pH--10.5-10.8
2. To be determined
3. Cl--800-1000 ppm
   $O_2$--none (controlled with sodium sulfite)
   pH--8.3-9.5 with $PO_4$
4. Chloride--991.0 ppm
   Phosphate--81 ppm
   $O_2$--40 ppm
   pH--10.5
5. Chloride--995.3 ppm
   Phosphate--58 ppm
   $O_2$--7.80 ppm
   pH--10.5
6. Chloride--106.5 ppm
   Phosphate--none
   $O_2$--7.85 ppm
   pH--11.5
7. Chloride--800 ppm
   Phosphate--50 ppm
   $O_2$--21% by volume
   pH--10.5
8. Chloride--800 ppm
   Phosphate--none
   $O_2$--21% by volume
   pH--10.5
9. Chloride--400 ppm
   Phosphate--none
   $O_2$--10% by volume
   pH--9.5
10. Chloride--1000 ppm
    $O_2$--Air sat. water, air as cover gas
    pH--8.3-9.5 with $PO_4$ water treat
11. Chloride--1000 ppm
    $O_2$--Air sat. water, air as cover gas
    pH--8.3-9.5 with NaOH
    $PO_4$--none
12. Chloride--0.5 ppm max
    Phosphate--150 ppm
    Sulfite--10 ppm
    pH--10 to 10.5
13. Chloride--0.5 ppm max
    Sulfite--10 ppm
    Total Solids--200 ppm max
    pH--9.5 ($PO_4$)
14. Chloride--1000 ppm
    pH--10 (NaOH)
    $O_2$--no treatment**
15. Chloride--1000 ppm
    pH--10 (33% $Na_3PO_4$ and 67% $Na_2HPO_4$)
    $O_2$--no treatment**
16. Chloride--800 ppm
    pH--10 (33% $Na_3PO_4$ and 67% $Na_2HPO_4$)
    $O_2$--no treatment**

* Operating times are cumulative to March 31, 1961.

**The secondary makeup tank will be maintained at 180° F, open to the atmosphere, which will maintain the oxygen concentration at somewhat less than 0.5 ppm.

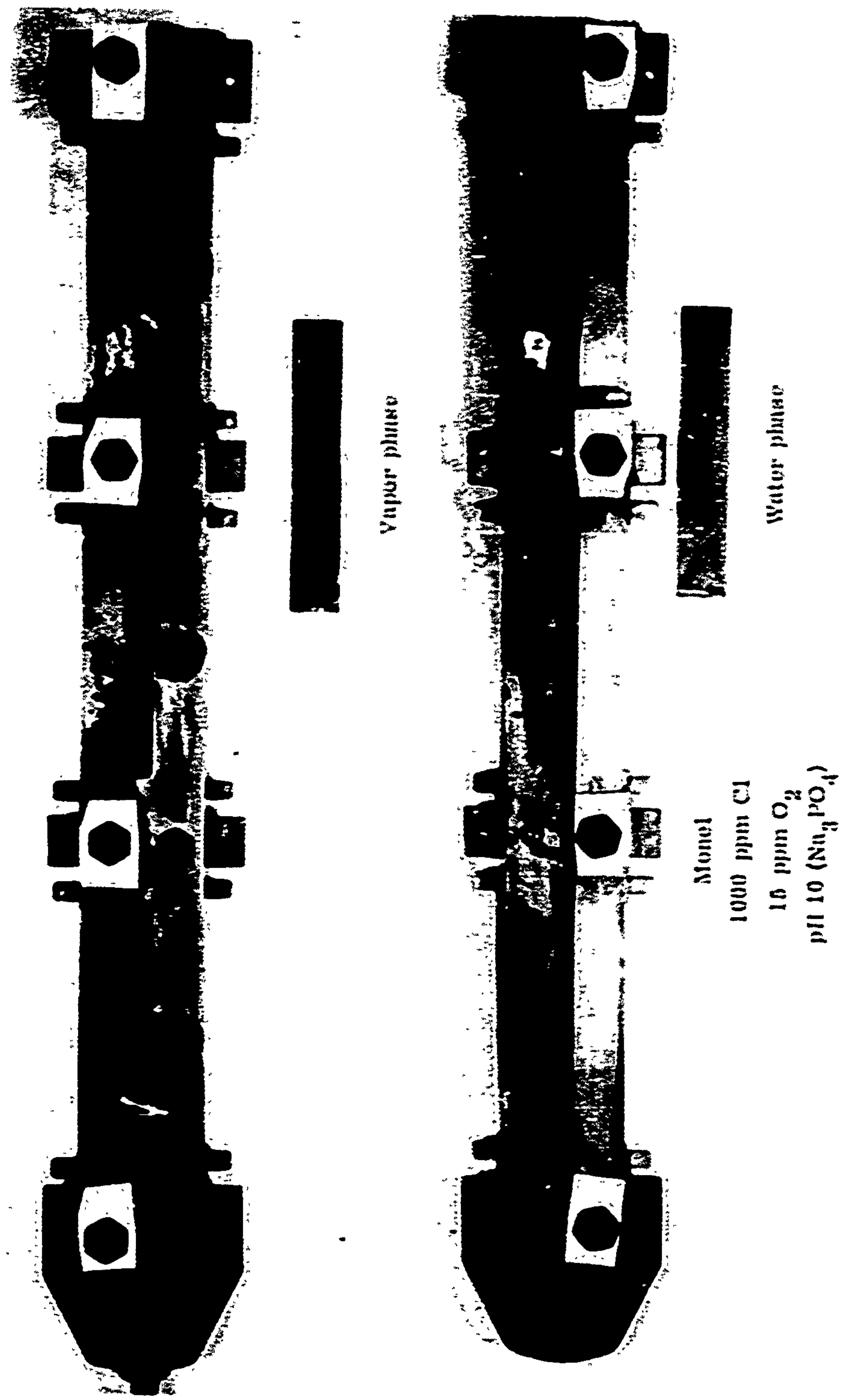



Fig. 1. Appearance of Monel Coupons as They Were Removed from the Autoclave

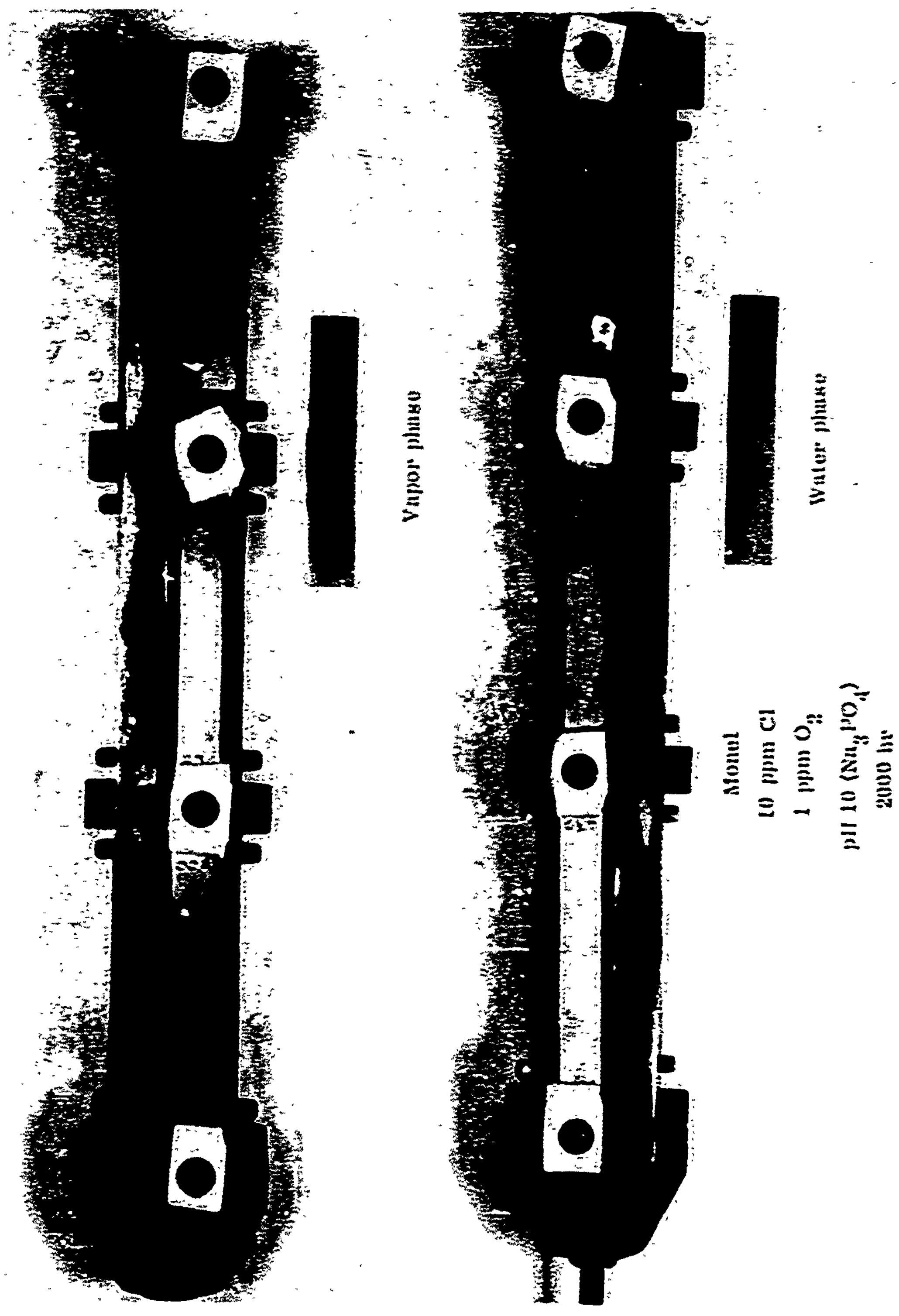



Fig. 2. Appearance of Monel Coupons as They Were Removed from the Autoclave

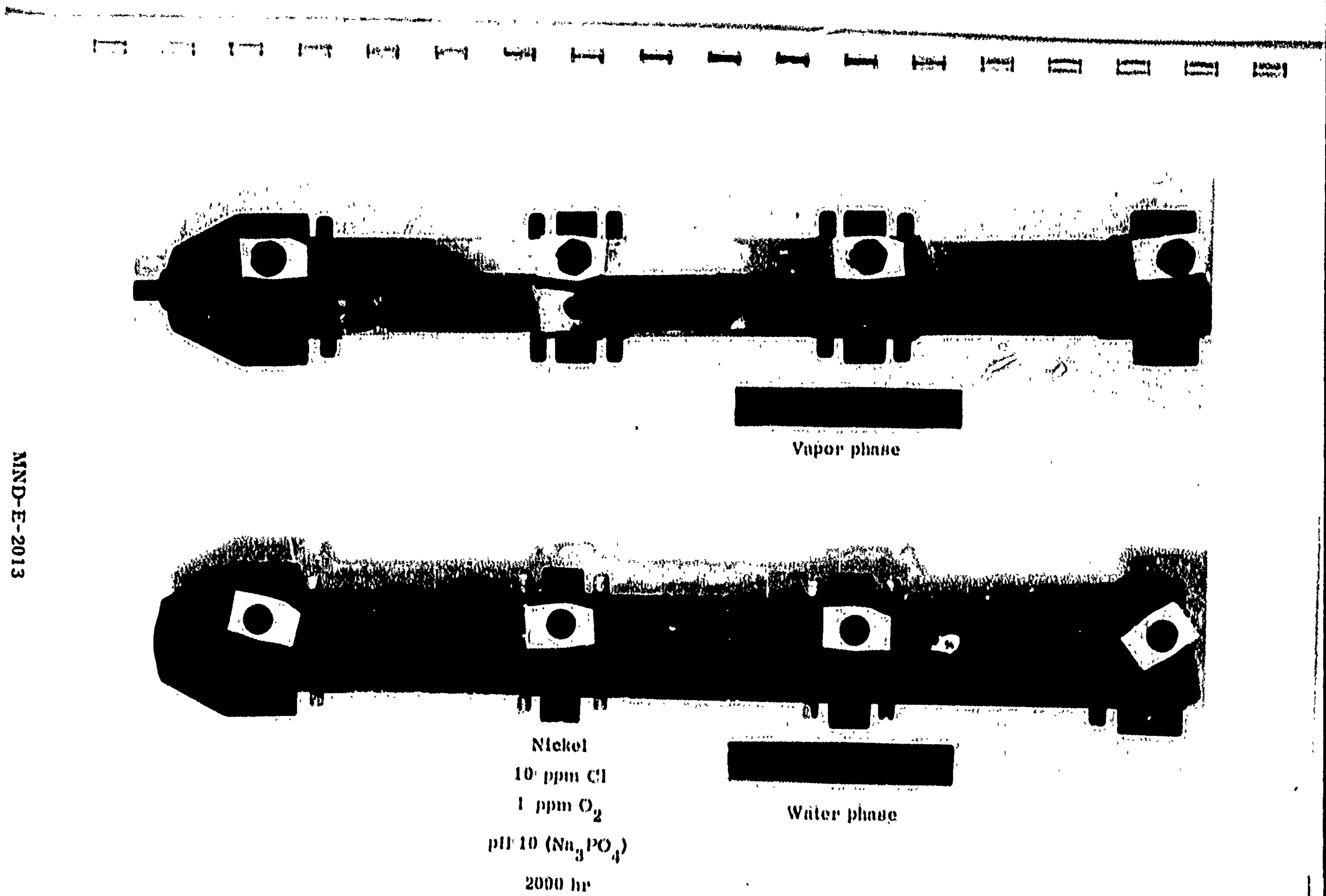



Fig. 3. Appearance of Nickel Coupons as They Were Removed from the Autoclave

The 2000-hour Inconel autoclave tests were delayed due to a material discrepancy. The material which was supplied as Inconel was analyzed and found to be a high chrome, iron-based alloy. Replacement material was obtained and pretest preparations were nearly complete at the end of the report period.

## 2. Analysis of Initial 2000-Hour Tests

All of the coupons from the initial 2000-hour tests were descaled, using the sulfamic acid process. Weight losses are listed in Table 2 along with the results from the 50- and 200-hour tests. Weight loss as a function of time for the two metals is plotted in Figs. 4 and 5. In general, the nickel corrosion rate appears to be somewhat lower than Monel for comparable conditions, the average values over the 2000-hour test period being 0.51 mdd for Monel and 0.37 mdd for nickel in the low oxygen, low chloride environment.

No cracking of any coupons has been observed. However, mild pitting corrosion occurred on Monel coupons in the vapor phase of the high chloride, high oxygen autoclave test (see Fig. 1). All 12 of the vapor phase coupons were pitted, while none of the liquid phase coupons suffered pitting. No significant difference in attack was noted between stressed and unstressed coupons or between annealed and stress-relieved coupons. Pitting generally occurred randomly over the tension and compression surfaces of the stressed specimens. The general appearance and distribution of pits may be seen in Fig. 6, which is a photograph of a portion of specimen No. 202. This coupon was stress-relieved prior to testing and was unstressed during the test. The pits were relatively large in area but shallow, the average depth being approximately 1 mil. A photomicrograph through one pit on specimen No. 731 (fully annealed) is shown in Fig. 7. Maximum penetration was 1.4 mils.

No pitting occurred on coupons in either the vapor or liquid phase of the low chloride, low oxygen tests.

# B. CORROSION LOOP OPERATION

Operation of the loop during the report period was virtually continuous; approximately 1840 hours of test time were logged. The test time accumulated for each vessel and for each day during the report period is indicated in Figs. 8, 9 and 10.

## 1. Loop Shutdown

The only major shutdown during the quarter was caused by failure of electrical terminals on one of the 50-kw primary line heaters. The spare heater-flange assembly was installed in the loop. The spare unit was

## TABLE 2

**Summary of Weight Loss Data From Autoclave Tests**

| | | | Monel | | | | | | Nickel | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10 ppm Chloride 1 ppm Oxygen | | | 1000 ppm Chloride 15 ppm Oxygen | | | 10 ppm Chloride 1 ppm Oxygen | | | 1000 ppm Chloride 15 ppm Oxygen | | |
| Hours | | | 50 | 200 | 2000 | 50 | 200 | 2000 | 50 | 200 | 2000 | 50 | 200 | 2000 |
| Annealed | S | V | 0.0 | 1.4 | 8.8 | 1.1 | 6.0 | 7.1 | 1.1 | 0.4 | 6.5 | 2.5 | 2.3 | |
| | | L | 0.3 | 1.2 | 11.3 | 0.2 | 2.2 | 6.3 | 0.6 | 0.7 | 5.8 | 0.5 | 2.6 | |
| | U | V | 0.1 | 1.1 | 10.8 | 1.8 | 6.0 | 8.5 | 0.9 | 0.5 | 4.9 | 2.5 | 1.5 | |
| | | L | 0.3 | 1.4 | 10.2 | 0.0 | 2.4 | 6.7 | 0.4 | 0.6 | 7.4 | 0.4 | 1.9 | |
| Stress-relieved | S | V | 0.6 | 2.5 | 7.9 | 1.6 | 4.9 | 9.2 | 1.2 | 0.8 | 8.8 | 1.9 | 2.5 | |
| | | L | 0.3 | 1.6 | 8.2 | 0.8 | 2.1 | 5.0 | 0.5 | 0.9 | 6.8 | 0.6 | 2.7 | |
| | U | V | 0.7 | 2.4 | 8.4 | 2.1 | 4.8 | 9.0 | 1.2 | 0.4 | 7.2 | 2.2 | 2.5 | |
| | | L | 0.3 | 1.5 | 6.7 | 0.7 | 1.9 | 7.6 | 0.6 | 0.8 | 6.0 | 1.2 | 1.3 | |
| Total | | | 2.6 | 13.1 | 72.3 | 8.3 | 30.3 | 60.4 | 6.5 | 5.1 | 53.4 | 11.8 | 17.3 | |

NOTE: Values are weight loss in milligrams--average of three specimens in all tests, pH adjusted to 10 with $Na_3PO_4$

S--Stressed to 90% at yield strength 0.02% offset

U--Unstressed

V--Vapor phase

L--Liquid phase

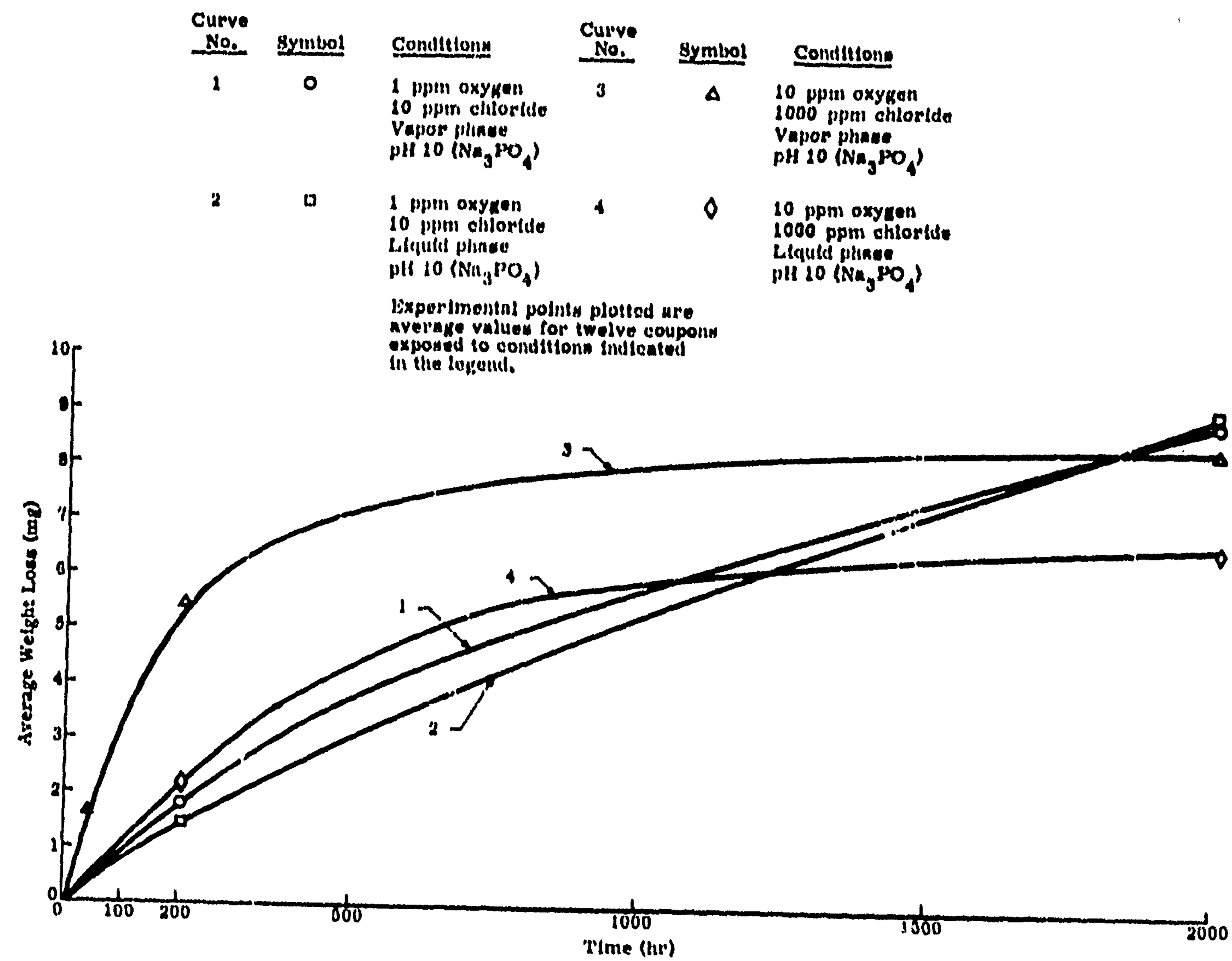



Fig. 4. Weight Loss as a Function of Time for Monel Coupons

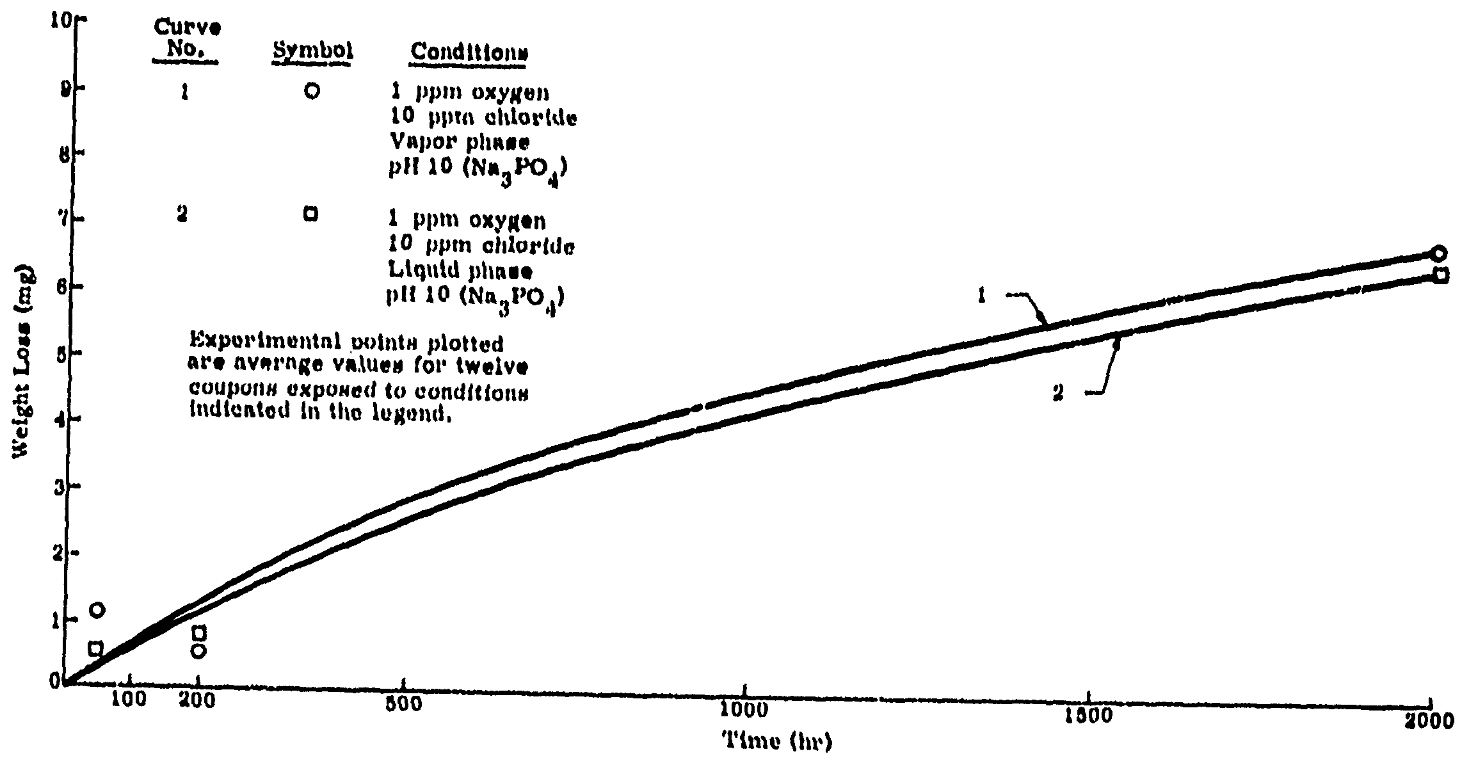
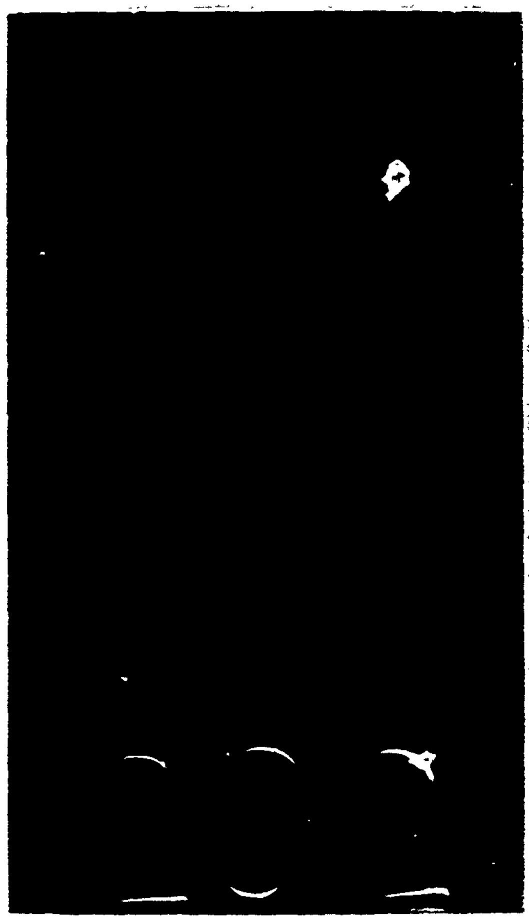



Fig. 5. Weight Loss as a Function of Time for Nickel Coupons



Autoclave conditions--1000 ppm chloride, 15 ppm oxygen, pH adjusted to 10 with $Na_3PO_4$, 2000-hour exposure; coupon was unstressed in vapor phase.

Fig. 6. Photograph of a Portion of Stress-Relieved Monel Coupon Showing Appearance and Distribution of Pits (6.5X magnification)

Autoclave conditions--1000 ppm chloride, 15 ppm oxygen, pH adjusted to 10 with $Na_3PO_4$, 2000-hour exposure.

Specimen conditions--Monel, fully annealed, stressed and in the vapor phase of the autoclave

Fig. 7. Photomicrograph Through Pit on Monel Coupon; Maximum Penetration, 0.0014 inch (250X magnification)

| Loop Vessel Designation | January | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| No. 1 Model | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 5.0 |
| No. 2 Model | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 1 Miniature | 0.5 | 0.0 | 23.5 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Miniature | 0.5 | 0.0 | 23.5 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 3 Miniature | 0.5 | 0.0 | 23.5 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 4 Miniature | 0.5 | 0.0 | 23.5 | 24.0 | 24.0 | 24.0 | 24.0 |
| | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| No. 1 Model | 0.0 | 18.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Model | 21.0 | 15.3 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 1 Miniature | 21.0 | 17.5 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Miniature | 21.0 | 17.5 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 3 Miniature | 21.0 | 15.5 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 4 Miniature | 21.0 | 18.3 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| No. 1 Model | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Model | 24.0 | 24.0 | 24.0 | 20.0 | 24.0 | 24.0 | 24.0 |
| No. 1 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Miniature | 24.0 | 24.0 | 21.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 3 Miniature | 24.0 | 24.0 | 24.0 | 22.2 | 24.0 | 24.0 | 24.0 |
| No. 4 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| No. 1 Model | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Model | 24.0 | 15.5 | 18.5 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 1 Miniature | 24.0 | 24.0 | 21.5 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 21.5 | 24.0 |
| No. 3 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 21.7 | 24.0 |
| No. 4 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 21.9 | 24.0 |
| | 29 | 30 | 31 | | | | |
| No. 1 Model | 24.0 | 24.0 | 24.0 | | | | |
| No. 2 Model | 24.0 | 24.0 | 24.0 | | | | |
| No. 1 Miniature | 24.0 | 24.0 | 24.0 | | | | |
| No. 2 Miniature | 24.0 | 24.0 | 24.0 | | | | |
| No. 3 Miniature | 24.0 | 24.0 | 24.0 | | | | |
| No. 4 Miniature | 24.0 | 24.0 | 24.0 | | | | |

| | | |
|---|---|---|
| No. 1 Model | MOD SG-4 and SH-4 | 1279.0 hr * |
| No. 2 Model | MOD SG-7 and SH-7 | 1324.4 hr * |
| No. 1 Miniature | MIN 10 | 1269.2 hr * |
| No. 2 Miniature | MIN 15 | 1269.3 hr * |
| No. 3 Miniature | MIN 11 | 1253.2 hr * |
| No. 4 Miniature | MIN 16 | 1258.0 hr * |

Times shown are number of hours of test time on vessel in 24-hour period, starting at 8:30 on the morning of that day in which the time is shown.

*Total hours of test time to January 31, 1961.

Fig. 8. Distribution of Test Time for Each Vessel During the Month of January

| Loop Vessel Designation | February | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 |
| No. 1 Model | | | | 24.0 | 24.0 | 22.0 | |
| No. 2 Model | | | | 24.0 | 24.0 | 22.0 | |
| No. 1 Miniature | | | | 24.0 | 24.0 | 22.0 | |
| No. 2 Miniature | | | | 24.0 | 10.0 | 22.0 | |
| No. 3 Miniature | | | | 24.0 | 24.0 | 22.0 | |
| No. 4 Miniature | | | | 24.0 | 24.0 | 22.0 | |
| | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| No. 1 Model | | 50-kw heater electrical terminal failure; line pump impeller replaced | | | | 21.0 | 24.0 |
| No. 2 Model | | | | | | 21.0 | 24.0 |
| No. 1 Miniature | | | | | | 21.0 | 24.0 |
| No. 2 Miniature | | | | | | 21.0 | 24.0 |
| No. 3 Miniature | | | | | | 21.0 | 24.0 |
| No. 4 Miniature | | | | | | 21.0 | 24.0 |
| | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| No. 1 Model | 12.0 | 23.0 | 24.0 | 24.0 | 24.0 | 18.1 | 24.0 |
| No. 2 Model | 12.0 | 23.0 | 24.0 | 24.0 | 24.0 | 18.1 | 24.0 |
| No. 1 Miniature | 12.0 | 23.0 | 24.0 | 24.0 | 24.0 | 18.1 | 24.0 |
| No. 2 Miniature | 12.0 | 23.0 | 24.0 | 24.0 | 24.0 | 18.1 | 24.0 |
| No. 3 Miniature | 12.0 | 23.0 | 24.0 | 24.0 | 24.0 | 18.1 | 24.0 |
| No. 4 Miniature | 12.0 | 23.0 | 24.0 | 24.0 | 24.0 | 18.1 | 24.0 |
| | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| No. 1 Model | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 17.8 | 24.0 |
| No. 2 Model | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 0.0 | 0.0 |
| No. 1 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 3 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 4 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| | 26 | 27 | 28 | | | | |
| No. 1 Model | 24.0 | 24.0 | 24.0 | | | | |
| No. 2 Model | 0.0 | 24.0 | 24.0 | | | | |
| No. 1 Miniature | 24.0 | 24.0 | 24.0 | | | | |
| No. 2 Miniature | 24.0 | 24.0 | 24.0 | | | | |
| No. 3 Miniature | 24.0 | 24.0 | 24.0 | | | | |
| No. 4 Miniature | 24.0 | 24.0 | 24.0 | | | | |

| | | |
|---|---|---|
| No. 1 Model | MOD SG-4 and SH-4 | 1776.9 hr * |
| No. 2 Model | MOD SG-7 and SH-7 | 1756.5 hr * |
| No. 1 Miniature | MIN 10 | 1773.3 hr * |
| No. 2 Miniature | MIN 15 | 1759.4 hr * |
| No. 3 Miniature | MIN 11 | 1757.3 hr * |
| No. 4 Miniature | MIN 16 | 1762.1 hr * |

Times shown are number of hours of test time on vessel in 24-hour period, starting at 8:30 on the morning of that day in which the time is shown.

* Total hours of test time to February 28, 1961.

Fig. 9. Distribution of Test Time for Each Vessel During the Month of February

| Loop Vessel Designation | March | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 |
| No. 1 Model | | | | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Model | | | | 8.0 | 24.0 | [illegible] | 0.0 |
| No. 1 Miniature | | | | 21.9 | 24.0 | 24.0 | 24.0 |
| No. 2 Miniature | | | | 21.9 | 24.0 | 24.0 | 24.0 |
| No. 3 Miniature | | | | 21.9 | 24.0 | 24.0 | [illegible] |
| No. 4 Miniature | | | | 21.9 | 24.0 | 24.0 | [illegible] |
| | 5 | 6 | 7 | | 9 | 10 | 11 |
| No. 1 Model | 2.0 | 22.8 | 24.0 | 24.0 | 24.0 | 24.0 | 21.0 |
| No. 2 Model | 0.0 | 22.8 | 24.0 | 24.0 | 24.0 | 18.0 | 0.0 |
| No. 1 Miniature | 2.0 | 22.8 | 24.0 | 24.0 | 24.0 | 24.0 | 21.0 |
| No. 2 Miniature | 2.0 | 22.8 | 24.0 | 24.0 | 24.0 | 24.0 | 21.0 |
| No. 3 Miniature | 2.0 | 22.8 | 24.0 | 24.0 | 24.0 | 24.0 | 17.0 |
| No. 4 Miniature | 2.0 | 22.8 | 24.0 | 24.0 | 24.0 | 24.0 | 22.0 |
| | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
| No. 1 Model | 0.0 | 2.5 | 17.0 | 21.8 | 24.0 | 24.0 | 23.0 |
| No. 2 Model | 0.0 | 22.0 | 17.0 | 23.4 | 22.8 | 24.0 | 24.0 |
| No. 1 Miniature | 0.0 | 22.0 | 17.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Miniature | 0.0 | 22.0 | 17.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 3 Miniature | 0.0 | 22.0 | 17.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 4 Miniature | 0.0 | 22.0 | 17.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| No. 1 Model | 0.0 | 22.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Model | 3.0 | 22.0 | 22.5 | 20.3 | 17.0 | 24.0 | 24.0 |
| No. 1 Miniature | 3.0 | 22.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 2 Miniature | 3.0 | 22.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 3 Miniature | 3.0 | 22.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| No. 4 Miniature | 4.5 | 22.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 |
| | 26 | 27 | 28 | 29 | 30 | 31 | |
| No. 1 Model | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | |
| No. 2 Model | 24.0 | 24.0 | 24.0 | 5.8 | 24.0 | 24.0 | |
| No. 1 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | |
| No. 2 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | |
| No. 3 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | |
| No. 4 Miniature | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | 24.0 | |

| | | |
|---|---|---|
| No. 1 Model | MOD SG-4 and SH-4 | 2413.0 hr* |
| No. 2 Model | MOD SG-7 and SH-7 | 2308.3 hr* |
| No. 1 Miniature | MIN 10 | 2433.0 hr* |
| No. 2 Miniature | MIN 15 | 2419.1 hr* |
| No. 3 Miniature | MIN 11 | 2413.0 hr* |
| No. 4 Miniature | MIN 16 | 2424.3 hr* |

Times shown are number of hours of test time on vessel in 24-hour period, starting at 8:30 on the morning of that day in which the time is shown.

* Total hours of test time to March 31, 1961.

Fig. 10. Distribution of Test Time for Each Vessel During the Month of March

fabricated with heavy-duty terminal lugs, and recurrence of the failure is not expected. In the assembly which failed, no damage was experienced by the heater elements. The terminals on this unit will be replaced with the heavy-duty type and the assembly will then be available as a spare.

When the new heater was installed in the loop, a pinhole leak was discovered where the elements are welded into the flange. The joint was welded in place, and no further difficulties were experienced with the assembly.

While the loop was shut down for replacement of the heater, the primary line pump was disassembled for inspection. The bearings were found to be worn and near the point of causing rotor damage. The accelerated bearing wear was caused by imbalance of the impeller. The impeller and bearings from the stand-by pump were installed in the in-loop pump and subsequent performance was entirely satisfactory. The impeller has been balanced and a new set of bearings obtained for future use.

Replacement of the heater assembly and repair of the pump were accomplished during a loop shutdown which extended from February 4 to February 9.

Shutdowns occurred during the month of March on three successive weekends while the loop was unattended. These shutdowns were initiated by low water levels in the model secondary systems. The loss of water was traced to two causes: (1) leakage across the secondary feedwater sight gauge gaskets and (2) leakage through tube fitting pipe threads. The gaskets were replaced, and the leaking pipe threads were seal-welded. The loop operated over the final weekend of March with no unusual drop of water level.

## 2. Maintenance of Secondary Environments

Difficulty was experienced during the quarter in maintaining the specified environments in the miniature secondary systems. The steam separators are not effectively removing entrained moisture from the steam and this results in carryover of chemicals from the vessels to the common storage tank. Since all heat exchangers do not have exactly the same steaming rate or the same specified environments, some vessels tend to operate above specifications while others run low.

Operation was improved by diverting the condensate return line to the drain rather than to the storage tank. This prevents exchange of chemicals from one vessel to another. Of course, environmental chemicals are still lost and addition of makeup chemicals must be made more often. Attempts are being made to obtain a more effective steam separator.

Chloride contamination of the model secondary systems was observed during the report period. Both systems were flushed several times to bring the chloride level below the specified limit. The source of the chloride was ultimately traced to salt deposits in the cooling coils used as condensers and blowdown coolers. The coils were used in the loop prior to the recent modifications, and subsequent cleaning operations apparently failed to remove all of the deposits. The coils were removed from the loop and thoroughly cleaned with nitric acid. A leak developed in one coil; this coil was replaced. Since these measures were taken, no difficulty has been experienced in maintaining the model secondary environments.

### 3. Operating Time Efficiency

During the report period, overall operation of the loop was quite satisfactory. A quantitative measure of performance may be obtained by computing the operating time efficiency (OTE) as follows:

$$\text{OTE} = \frac{\text{Total hours of test time (all vessels)}}{\text{Total possible hours of test time (all vessels)}} \times 100\%$$

Figure 11 shows the OTE achieved since the start of test work. It can be seen that utilization of the loop was greatly improved during the quarter. The initial low values resulted from the intermittent operation when argon was used to pressurize the primary system. The OTE during this quarter has been high, except for that time lost because of the 50-kw line heater failure. It is expected that the cumulative OTE will approach 85% by the end of the next quarter. This is estimated to be near the practical limit, when allowances are made for downtime resulting from normal loop maintenance.

## C. CORROSION VESSEL TESTING

### 1. Model Heat Exchangers

Testing of the bimetal (MOD SX-4) model vessels and the Inconel (MOD SX-7) model vessels was initiated during the quarter. The secondary environment in the Inconel vessels is as follows (PM-1 conditions):

| | |
|---|---|
| pH | 10 to 10.5 |
| $PO_4$ | 150 ppm |
| $SO_3$ | 10 ppm |

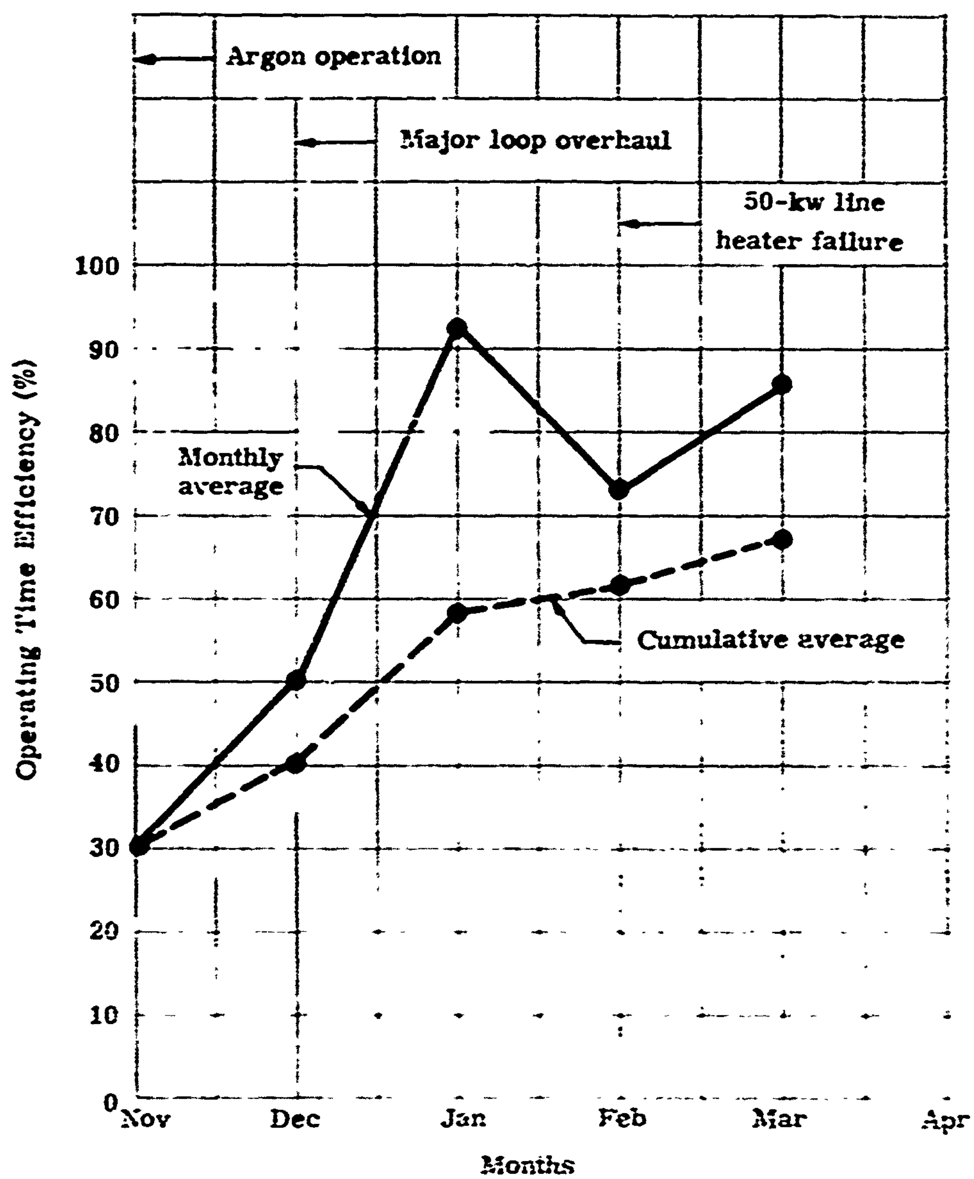



Fig. 11. Summary of Loop Operating Efficiency

| | |
|---|---|
| Cl | 0.5 ppm (max) |
| Total solids | 175 to 200 ppm |

The secondary environment for the bimetal vessels is as follows (SM-1 water conditions):

| | |
|---|---|
| pH | Approximately 8.5 with $Na_3PO_4$ |
| Cl | 0.5 ppm (max) |
| $O_2$ | 0.5 ppm (max) |
| Total solids | 200 ppm (max) |

Accumulated test time, as of March 31, is as follows:

| | |
|---|---|
| MOD SX-4 | 1413 hr |
| MOD SX-7 | 2308 hr |

A regular schedule of water sampling and analysis has been established. Boiler water and condensate are sampled and analyzed Monday, Wednesday and Friday of each week. Makeup chemicals are added as required.

## 2. Miniature Heat Exchangers

Testing of the miniature Inconel (MIN 10 and 11) and bimetal (MIN 15 and 16) miniature heat exchangers was continued during the quarter. Accumulated test times are as follows:

| | |
|---|---|
| MIN 10 | 2433 hr |
| MIN 11 | 2413 hr |
| MIN 15 | 2419 hr |
| MIN 16 | 2424 hr |

The secondary environments for these vessels are summarized as follows:

MIN 10

| | |
|---|---|
| Cl | 1000 ppm |
| pH | 10 (with NaOH) |
| $O_2$ | No treatment (see note) |

MIN 11

| | |
|---|---|
| Cl | 1000 ppm |
| pH | 10 (with mixture of 33% $Na_3PO_4$ and 67% $Na_2HPO_4$) |
| $O_2$ | No treatment (see note) |

MIN 15 and 16

| | |
|---|---|
| Cl | 800 ppm |
| pH | 10 (with mixture of 33% $Na_3PO_4$ and 67% $Na_2HPO_4$) |

NOTE: The secondary makeup tank is maintained at 180° F, open to the atmosphere, which will maintain the oxygen concentration at somewhat less than 0.5 ppm.

In MIN 15 the bimetallic tubing has been defected, exposing the stainless steel sublayer to the secondary environment. Defects are in the vapor phase, the liquid phase and at the vapor-liquid interface.

A regular schedule of water sampling and analysis has been established. Boiler water and condensate are sampled and analyzed Monday, Wednesday and Friday of each week. Makeup chemicals are added as required.

3. Reduction of Heat Transfer Data

Reduction of heat transfer data was started during this report period; the heat transfer index for each model steam generator has been determined as a function of time since testing was initiated. The index is a qualitative measure of the overall coefficient of heat transfer of the vessel. Because scale or corrosion products affect the quantity of heat transferred, the index should give an indication of scale buildup and a measure of its effect on the heat transfer rate in the generator.

The derivation of the index is as follows:

$$\text{Heat transfer index} = \frac{\text{Heat transfer to secondary fluid}}{\text{Primary fluid heat available for transfer}}$$

or

$$\text{Heat tranafer index} = \frac{W_s\,(H_{so} - H_{si})}{W_p\,(H_{pi} - H'_{po})} \qquad (1)$$

where

$W_s$ = Secondary steaming rate (lb/hr)

$W_p$ = Primary flow rate (lb/hr)

$H_{si}$ = Enthalpy of secondary water in (Btu/lb)

$H_{so}$ = Enthalpy of secondary steam out (Btu/lb)

$H_{pi}$ = Enthalpy of primary water (Btu/lb)

$H'_{po}$ = Enthalpy of primary water out, if at the secondary steam saturation temperature.

After the data were carefully examined, it was determined that a more accurate index could be determined by using the primary fluid measurements because those data were taken more often during the test. The heat balance for the steam generator may be written:

$$W_s = (H_{so} - H_{si}) = W_p (H_{pi} - H_{po}) - Q_L \qquad (2)$$

where

$H_{po}$ = Enthalpy of primary water out (Btu/lb)

$Q_L$ = Thermal losses from the steam generator (Btu/hr).

Substituting in Eq (1) and reducing:

$$\text{Heat transfer index} = \frac{(H_{pi} - H_{po}) - Q_L/W_p}{(H_{pi} - H'_{po})} \qquad (3)$$

Examination of the data shows that the quantity $Q_L/W_p$ is very small compared to the quantity $(H_{pi} - H'_{po})$ so that the use of an experimentally determined constant value for $Q_L/W_p$ has no appreciable affect on the index.

Figures 12 and 13 show the results of the present data reduction effort. The curves appear to indicate that large effects on heat transfer by scaling have not occurred. Analysis of these data is still being conducted. Also, possible causes for the large deviation of a few scattered points are being investigated.

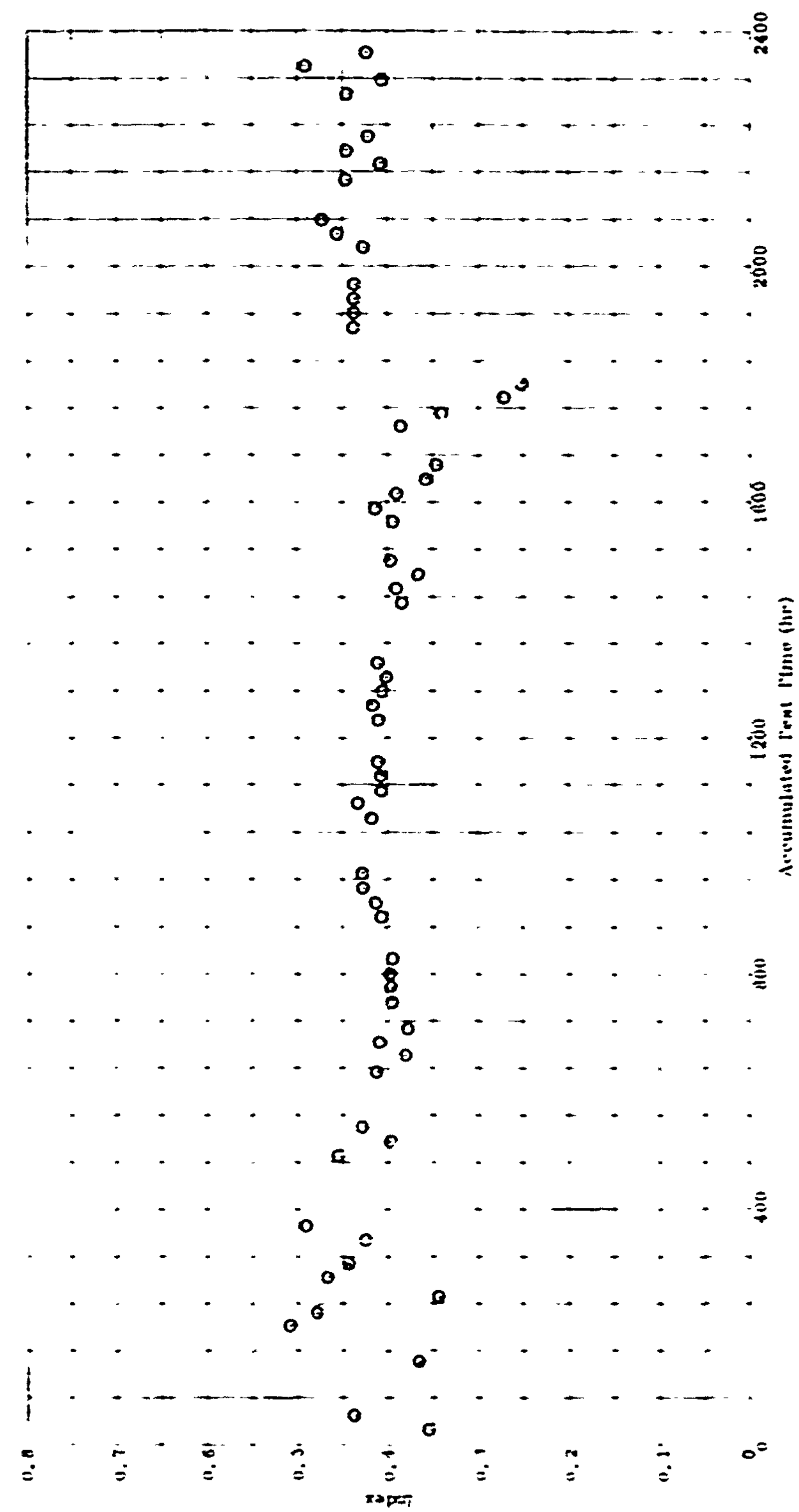



Fig. 12. Variation of Calculated Heat Transfer Index with Time--Bimetal Steam Generator (MOD SG-4)

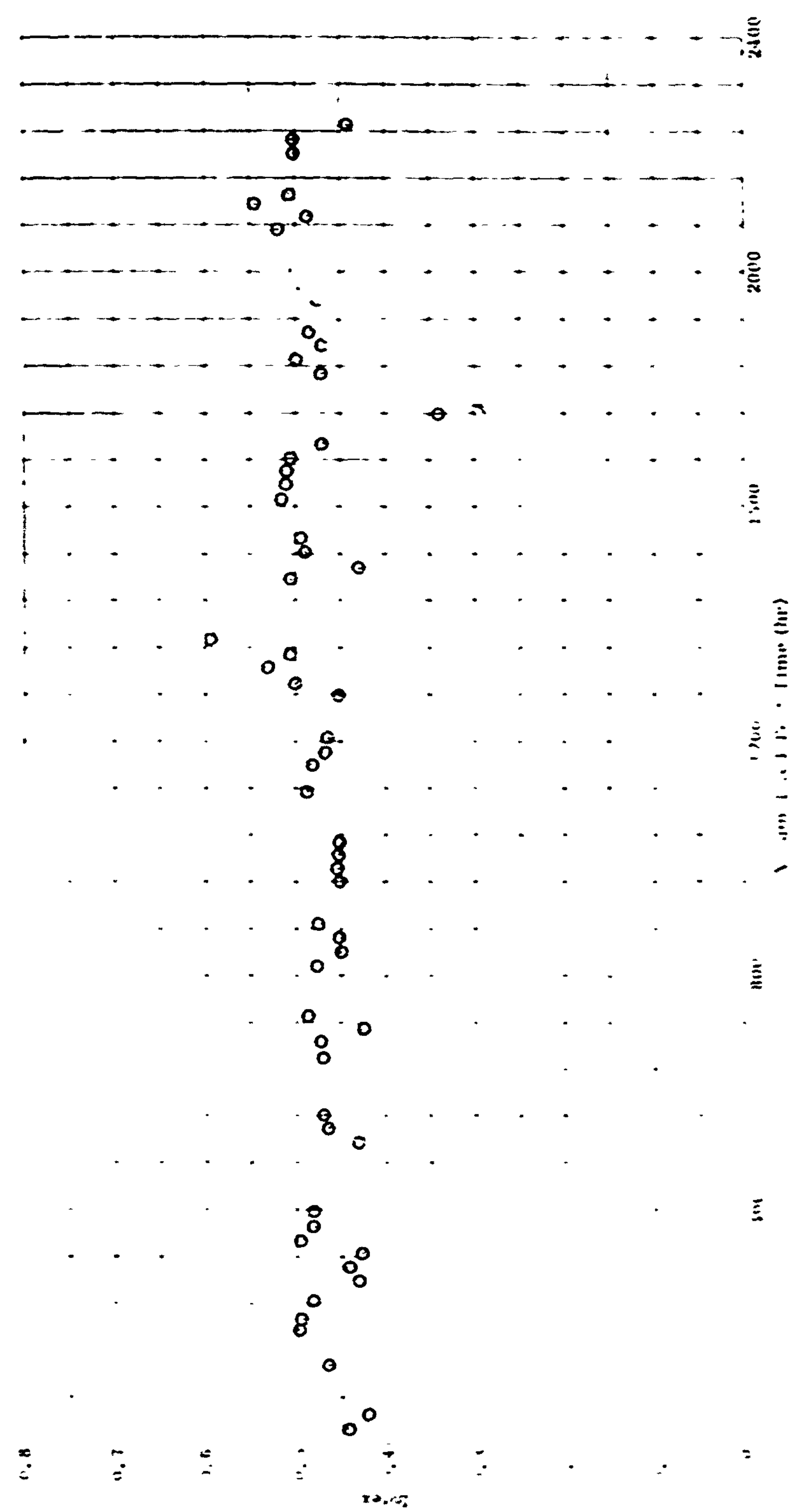



Fig. 13. Variation of Calculated Heat Transfer Index with Time--Inconel Steam Generator (MOD SG-7)